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Residential past and future energy consumption: Potential savings and environmental impact

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ABSTRACT

In order to identify main drivers behind changes in electricity and fuel consumptions in the household sector in Jordan, two empirical models are developed based on multivariate linear regression analysis. In addition, this paper analyzes and evaluates impacts of introducing some efficient measures, such as high efficiency lightings and solar water heating systems, in the housing stock, on the future fuel and electricity demands and associated reduction in GHG emissions. It was found that fuel unit price, income level, and population are the most important variables that affect demand on electrical power, while population is the most important variable in the case of fuel consumption. Obtained results proved that the multivariate linear regression models can be used adequately to simulate residential electricity and fuel consumptions with very high coefficient of determination. Without employing most effective energy conservation measures, electricity and fuel demands are expected to rise by approximately 100% and 23%, respectively within 10 years time. Consequently, associated GHG emissions resulting from activities within the residential sector are predicted to rise by 59% for the same period. However, if recommended energy management measures are implemented on a gradual basis, electricity and fuel consumptions as well as GHG emissions are forecasted to increase at a lower rate.

Contents

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1. Introduction

Jordan, which is a relatively small country of about 5.6 million inhabitants, lies in the heart of the Middle East. It is among the low-income countries of the region with an average GDP per capita of about US$ 2550 in 2006, compared to US$ 10,000–18,000 for neighboring oil exporting Arab Gulf States [1,2]. The country suffers from an ever-present lack of sufficient supplies of natural resources including water, minerals, crude oil and natural gas. Being a non-oil producing country, there has been an increasing anxiety about energy consumption and its harmful impact on the national economy as well as local environment. At present, Jordan depends profoundly on imported crude oil and natural gas from neighboring Arab countries as main sources of energy which causes a drain of scarce hard currency. The annual energy bill has been hurriedly escalating over the past few years and exceeded US$ 3 billion in year 2006 due to high rates of population and economic growth combined with the successive increase in oil price.

The residential sector in Jordan has been affected more than any other sector by the economic and technological changes witnessed in the country. For example, in the 1960s and 1970s, kerosene was the major fuel used for cooking and water heating in urban areas in Jordan. Electricity was not widespread, and most dwellings did not have electrical appliances such as refrigerators and television sets. Gas cookers and gas heaters also were not common, particularly among low-income families. Currently, liquefied petroleum gas (LPG) is the main fuel used for cooking and water heating. Electricity is available for almost all households, which employ a large variety of different electrical appliances [3]. The residential sector is divided into two main sub-sectors: rural and urban. The latter, forms almost 80% of the total inhabitants at present. In 1994, the average family sizes were 6.65 and 7.49 members for urban and rural sub-sectors, respectively, while in 2004 these dropped to about 5 and 6, respectively, with an average of 5.4 for whole of the country. More than 80% of the population lives in dwellings that range from 50 to 200 m^2. The distribution of income in Jordan, however, is very disproportionate. The wealthiest 10% of households earn more than 50% of the total national household income, while the poorest 48% earn only about 10% of the total household income, and live below what is accepted to be the poverty level: the average monthly income per family is approximately US$ 300–400 [4]. Lack of adequate housing and access to basic services are also indicators of poverty: at present more than a quarter of the population live in miserable conditions, e.g. permanent Palestinian refugee camps or marginal houses, far below basic acceptable levels. About 61% only of all households have access to a sewage network [5].

Improving the end-use energy efficiency is one of the most effective ways to reduce energy consumption in the residential sector and associated pollutant emissions. As in most developing countries, substantial energy losses exist in a large number of houses in Jordan. Reduction of such losses would improve energy efficiency significantly, which means less reliance on energy imports, and less CO_2 emissions. Lately, several papers have shown that implementing few options, such as use of more efficient lighting and refrigerators, thermal insulation of buildings, efficient space and water heating, demand-side management and fuel substitution, in the residential sector could reduce energy consumption and CO_2 emissions [6–11]. In spite of the existence of several studies attempting to analyze current and future energy requirements for the residential sector in Jordan [12,13], there is still need for empirical models to analyze and explain the main driving forces behind fuel and electricity consumptions change, for the residential sector, since energy planning is not possible without a deep knowledge and analysis of past and present consumption. Therefore, and in order to support on going and future energy-related research and policies, fuel and electricity consumption models based on the multivariate linear regression method are developed in this paper. Such models would help energy policy planners in understanding the implications of changes in the exogenous variables when the underlying relationships are fairly stable. The establishment of such models will form the first objective of this paper. Also, in open literature, no study was found trying to evaluate and project potential energy savings in the Jordanian residential sector; therefore, the second objective of this paper being forecasting fuel and electricity consumptions during next decade and evaluating impacts of introducing high efficiency lightings and solar water heating (SWH) systems on future fuel and electricity consumptions and associated reduction in CO_2 emissions. The developed models have the advantages of being simple and able to evaluate and predict potential energy savings.

2. Energy and environment in Jordan

Although Jordan has plentiful supplies of new and renewable energy sources, such as oil shale and solar energy; nevertheless, crude oil has principally dominated the Jordanian energy sector for the last four decades and it has been the chief primary energy source for economic and social developments. Recently, imported natural gas (NG) from Egypt is used to substitute for heavy fuel oil (HFO) and diesel fuel in the main power plants. Table 1 shows fossil fuels consumption during 2006 [2]. In terms of energy equivalent value, HFO, diesel, gasoline, and NG represent more than 87% of all types of fuel consumed in Jordan. This is because NG and HFO are used in electricity generation and large industrial plants. Diesel fuel is employed mainly for transportation, industry and to a lesser extent for space heating and agriculture. Liquefied petroleum gas is mainly used for cooking and space heating purposes in household, commercial and agricultural sectors.

In 2006, electricity and final energy consumptions reached nearly 9579 GWh and 6666 ton oil equivalent (toe), respectively; of these the residential sector had shares equal to 36% and 22% of the total electricity and final energy consumptions, respectively [2]. Figs. 1 and 2 show the percentage share of sectoral final energy and electricity consumptions in 2006. The term “others” in these figures includes agriculture, street lightings and other minor sectors such as government and military consumptions.

In Jordan, residential energy requirements may vary from one province to another, depending on the standard of living, type and age of dwelling, climate conditions and availability of different

Table 1
Fossil fuels consumption in Jordan during 2006.

Fuel type	Consumption ($\times10^3$ ton)[a]	Energy equivalent ($\times10^3$ toe)	Percentage of total (%)
LPG	313	350.7	5.3
Gasoline	741	771.8	11.6
Jet fuel	300	312.4	4.7
Kerosene	150	155.0	2.3
Diesel fuel	1837	1870.9	28.1
Heavy fuel oil	1333	1208.8	18.1
Natural gas	1600×10^6 N m^3	1995.9	29.9
Total		6665.5	100

[a] Except where shown.

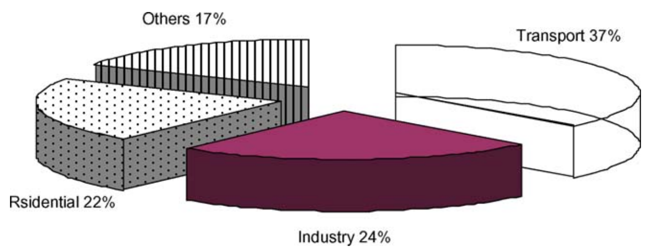

Fig. 1. The percentage share of sectoral consumption of final energy in Jordan for 2006.

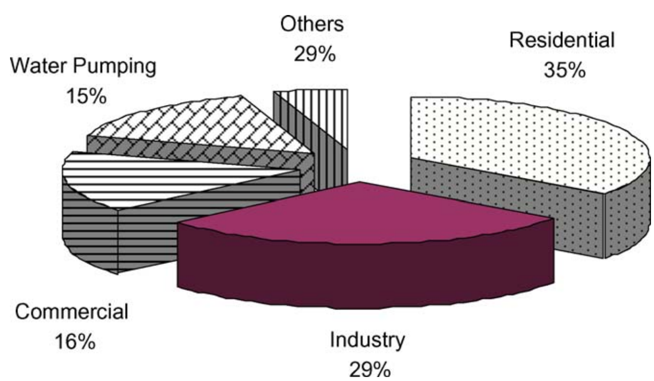

Fig. 2. The percentage share of sectoral consumption of electricity in Jordan.

forms of commercial energy sources. Electricity is mostly consumed through lightings and electrical appliances. Kerosene, LPG, and diesel are main fuel forms employed in the residential sector and are mostly used for space and water heating. However, LPG is the main fuel used for cooking purposes in both urban and rural regions, with the exception of few thousands of Bedouins living in remote areas, such as eastern and southern deserts, still use wood and biomass for heating and cooking. However, such

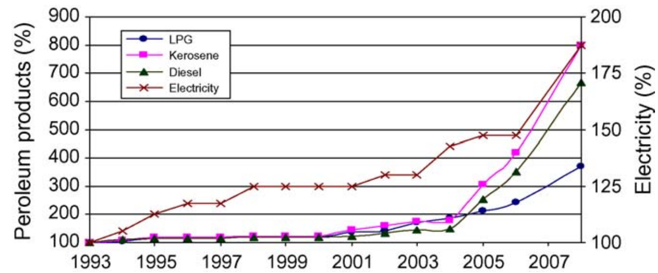

Fig. 3. Relative unit price increase of different energy forms used in households.

pattern is expected to change due to the recent sharp price increase of energy forms, especially those used heavily in the residential sector—see Fig. 3. As can be seen, kerosene and diesel unit prices' increased by 800% and 670%, respectively, as compared to prices prevailed in the base year, 1993, when the economic-reform and adjustment national plan initiated and aimed to achieve sustainable growth in the productive sectors. LPG and electricity unit prices' were increased but at lower rates of about 375% and 190%, respectively. The current adopted policy of the government of Jordan for pricing petroleum products is to follow monthly rolling average of refined products in the international market after adding transportation and distribution costs. As a result of such increase on fuel prices, local low quality solid fuels, e.g. olives waste resulting from olive oil production and wood, witnessed higher rates of demand and become popular, even though their prices increased significantly.

In addition to energy use, the associated greenhouse gas (GHG) emissions and their potential effects on the global climate change are nowadays a worldwide concern. The recognition of the danger posed by continued emission accumulation of greenhouse gases into the atmosphere has led to the Rio and Kyoto summits on climate change in 1992 and 1997, respectively, and the UN framework convention on climate change. CO_2 is the most important GHG, and most of its emissions come from combustion of fossil fuels in all sectors of the economy, i.e. energy supply chain and final users. Jordan has signed and adopted almost all the international and regional conventions relating to environmental protections. Among these are the Biological Diversity and Climate Change Convention, which were approved during the Earth Summit in Rio de Janeiro in 1992. Jordan's annual CO_2 emissions were estimated in 2004 to be 16.70×10^6 ton [14]. Although this constitutes less than 0.1% of the world's annual CO_2 emissions, its intensity is considerably high: about four times that of most Western European countries, and almost similar to those of oil producing Arab countries as indicated in Fig. 4 [15]. This implies that there is room for energy efficiency improvement and emissions reduction in all sectors.

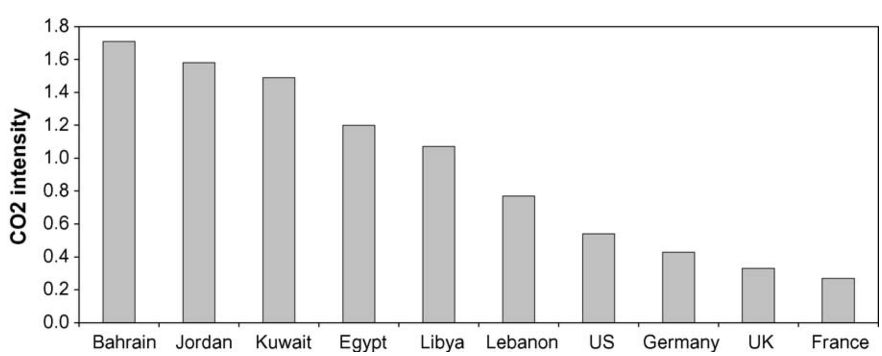

Fig. 4. CO_2 emissions intensity in selected Middle Eastern and OECD countries (kg CO_2/2000 US$).

3. Methodology

Energy modeling is a subject of widespread current interest among engineers and scientists concerned with problems of energy production and consumption. Energy modeling in some areas of application is now capable of making useful contributions to planning and policy formulation [16]. Several models have been proposed to model residential energy consumption that range from relatively simple ones, such as that developed by Mayer and Benjamini [17] which consists of a simple two-parameter model of the monthly demand for natural gas for space heating to a more complex one, such as that used by Ugursal and Fung [18]. The latter, which is called engineering method in the literature, involves developing a housing database representative of the national housing stock and estimating the energy consumption of the houses in the database using a building simulation program. The conditional demand analysis (CDA) method was also used by several authors and was first introduced by Parti and Parti [19]. CDA is a regression-based method in which the regression attributes consumption to end-uses on the basis of the total household energy consumption. Recently, the neural network (NN) method has been utilized to model residential energy consumption [20–23]. Through NN method, it is possible to determine causal relationships among a large number of parameters. A comparison of neural network, conditional demand analysis, and engineering approaches for modeling end-use energy consumption in the residential sector can be found in Ref. [22]. Lately, researchers used the genetic algorithm (GA) approach [24] to estimate the future projections of energy input to residential–commercial sector.

In this paper, and according to the available data and deemed goals, the general model approach, which is based on multivariate regression analysis, is used. This method has proven to be an effective tool to analyze and identify different factors that affect fuel and electricity consumptions in different sectors [25–27]. It should be noted here that the regression method used to achieve the first objective of this study, i.e. identifying the main factors affecting the historical fuel and electricity consumptions, is generally valid over the region of regressor variables contained in the observed data. Montegomery and Runger [28] have discussed dangers of extrapolation when using a regression model for prediction; therefore, this study uses a technique based on time series analysis to predict the future energy demand and develops a mathematical approach to analyze and evaluate impacts of different energy efficiency measures on fuel and electricity consumptions in the Jordanian residential sector.

3.1. The multivariate regression model

Regression analysis is a statistical technique that involves exploring the relationships between two or more variables through building a model equation that relates the response (variable of interest) to a set of predictor variables. The starting point of this analysis is to define the response variable and the potential factors (predictor variables) that are important to explain the response's behavior. In this study, energy consumption is the response variable. There are different factors that can be considered to be significant for determining energy demand of the residential sector, the most important parameters selected, in the current analysis, as causal variables are as follows: population (P), income level (I), weather conditions (W), and energy prices ($E\$$ and $F\$$). Each of these variables is explained briefly hereafter, including reasons for their use in the proposed models.

3.1.1. Population (P)

As the population increases, the number of households increases, and consequently, number of energy-consuming appliances increases; therefore, residential energy demand would arise.

3.1.2. Income level (I)

As the income level increases, living standard would raise, e.g. acquiring and using more home appliances which consume high rates of energy such as air-conditioning units. In this study, the GDP per capita is taken as a variable indicating the income level. As per capita income levels increase, it is expected to see higher appliance saturation rates and higher rates of utilization. However, if both energy prices and per capita income levels increase simultaneously, it is unclear whether energy use will rise or fall; this depends greatly on relative strength of unit energy price or income level effect.

3.1.3. Electricity unit price (E$)

As electricity tariff increased, a person is expected to respond by employing more efficient appliances or switching to another source of energy; thus, expected rates of electricity consumption would be reduced.

3.1.4. Fuel unit price (F$)

Kerosene, LPG, and diesel are most common fuels used in Jordan's residential sector for space heating and to a lesser extent for domestic water heating. It is expected that when unit price of fuel increased, households will respond by reducing their consumption of fuel or switching to electricity as a substitute to fuel. In this study, the weighted average prices of kerosene, LPG, and diesel are taken as a variable.

3.1.5. Weather conditions (W)

Ambient temperature is the most important weather variable that may affect energy use. With hot and dry summers and cold winters cause more intensive use of space heating and cooling appliances; therefore, energy consumption could be correlated directly to ambient temperature either in summer or winter seasons. However, the appropriate climate variable could not be an average annual temperature, but rather the difference between annual average temperatures during summer and winter.

The multivariate regression models for fuel and electricity consumptions are then

$$(F)_t = \mu_0 + \mu_1 P_t + \mu_2 I_t + \mu_3 (E\$)_t + \mu_4 (F\$)_t + \mu_5 W_t + \varepsilon_t \quad (1)$$

$$(E)_t = \mu_0 + \mu_1 P_t + \mu_2 I_t + \mu_3 (E\$)_t + \mu_4 (F\$)_t + \mu_5 W_t + \varepsilon_t \quad (2)$$

where F and E are fuel and electricity consumptions, respectively, μ_0 regression model intercept, μ_j represents regression model coefficient (j = 1, 2, 3, 4, 5), t represents year t, and ε_t difference between actual and predicted energy consumption.

3.2. Evaluating savings from introducing efficiency measures

The following analysis aims to evaluate electricity and fuel savings, installed capacity savings, and environmental impact resulting from the implementation of efficient practices, i.e. high efficiency lightings and SWH systems, in the Jordanian residential sector.

3.2.1. Energy consumption savings

Due to the lack of policy models able to capture the full effects of adopting energy efficient measures, this study uses the scenario

approach for this analysis. Scenarios are tools for ordering one's perception about alternative future options, and the end result might not be an accurate picture of tomorrow but can give better decisions about the future. No matter how things might actually turn out, both the analyst and the policy maker will have a scenario that resembles a given future, and that will help us think through both the opportunities and the consequences of that future. In this study, five different scenarios are suggested:

- *Scenario A*: The situation will remain unchanged during the study period.
- *Scenario B*: The high efficiency measures will take a yearly constant full share of the new houses from 2008 until 2018.
- *Scenario C*: The high efficiency measures will take a yearly constant share of 50% of the new houses from 2008 until 2018.
- *Scenario D*: The share of high efficiency measures will progressively increase to 100% of the new houses from 2008 until 2018.
- *Scenario E*: The share of high efficiency measures will progressively increase to 50% of the new houses from 2008 until 2018.

The suggested shares for scenarios B and C are justified by the continuously increasing prices of different forms of energy in Jordan, which was witnessed recently in March 2008. Scenarios D and E assume a more gradual and conservative approach in introducing high efficiency measures into the local market. For all five scenarios the following assumptions are made:

- The share of diesel, kerosene, and LPG will remain constant over the projected period.
- Electricity cost is about 0.1 \$/kWh based on the new tariff adopted by the government of Jordan as in March 2008.
- Kerosene, diesel, and LPG prices are assumed to be 21.2, 23.9, and 29 \$/GJ based on the new tariff adopted by the government of Jordan as in March 2008.
- Coverage percentage of the residential energy consumption for incandescent lighting, fuel water heating, and electrical water heating are assumed to be as: 8.85%, 9.13%, 10.72%, respectively, as estimated by a previous study of energy and exergy use in the Jordanian urban residential sector [13].
- Installed capacity cost (infrastructure cost to generate electricity) is taken as an average of about 1128 \$/kW installed.
- Duration of study is taken as next 10 years. Practices prior to the period of study will gradually convert to the proposed practices. This conversion is assumed to be uniform (i.e. one-tenth each year) along the duration of the study. The efficient yearly share penetration of converted old practices will be taken as assumed for the previous scenarios regarding new houses.
- Specific CO_2 emission coefficient of electricity generation (0.462 kg CO_2/kWh) is taken as weighted average of all power plants in Jordan during year 2007. Also, specific CO_2 emission coefficient of fuel consumption is taken as 0.055 kg CO_2/MJ, which is the weighted average of all combustible fuels used in the residential sector for the purpose of domestic water heating.

To evaluate the potential savings at period t $(ES)_t$ for scenarios B and C, the following model is developed and employed in this investigation:

$$(ES)_t = SF \times CP \times MS \times \left[\left(\frac{EE_0 \times t}{T}\right) + (EE_t - EE_0)\right] \tag{3}$$

In Eq. (3), SF represents the saving factor resulting from introducing the end-use efficiency measure, CP is energy coverage percentage of the end-use within the residential sector, MS proposed market share of the end-use efficiency measure, EE_0 energy consumption of the residential sector at base year 0 (2008 in this study), EE_t predicted energy consumption of the residential sector for year t, and T study period length (from 2008 to 2018).

Eq. (3) can be rewritten as

$$(ES)_t = SF \times CP \times \left[MS\left(\frac{EE_0}{T}\right)_1 + \cdots + MS\left(\frac{EE_0}{T}\right)_t + MS(EE_t - EE_{t-1}) + MS(EE_{t-1} - EE_{t-2}) \cdots + MS(EE_1 - EE_0)\right] \tag{4}$$

or

$$(ES)_t = SF \times CP \times \left[\sum_{i=1}^{t} MS\left(\frac{E_0}{T}\right)_i + \sum_{i=1}^{t} MS(E_i - E_{i-1})\right] \tag{5}$$

However, this model assumes that both the uniform converted portion of the base energy consumption as well as the increase in energy consumption over the base year of the Jordanian residential sector would be at assumed market share of energy efficient measure. However, to be conservative, this share will be assumed to be taken place progressively during the study period. Hence, the model becomes:

$$(ES)_t = SF \times CP \times \left[\sum_{i=1}^{t}\left(\left(\frac{i}{T}\right) MS\left(\frac{EE_0}{T}\right)\right) + \sum_{i=1}^{t}\left(\left(\frac{i}{T}\right) MS(EE_i - EE_{i-1})\right)\right] \tag{6}$$

where $1 \leq t \leq T$.

The energy cost savings can be obtained by multiplying the energy saving by the unit price of energy.

3.2.2. Installed capacity savings

Demand savings will result from using high efficiency electrical appliances, with smaller capacities compared to existing large and inefficient conventional appliances, which would reduce the installed capacity within the residential sector and consequently lower peak-demand loads per unit of time inevitable. Therefore, utilities will most probably spend less investment in the future for expansion projects starting from new power stations down to distribution networks due to expected lower rates of growth. The annual installed capacity savings, ICS_t, can be estimated as follows:

$$ICS_t = MDS_t \times ICC \tag{7}$$

where ICC is the installed capacity cost and is estimated to be 1128 US\$/kW installed, based on past power generation projects in Jordan [29], and MDS the annual demand savings and can be estimated as

$$MDS_t = \frac{ES_t}{AOH} \tag{8}$$

where AOH is annual operation hours.

3.2.3. Environmental impact

Introducing high-energy efficiency practices will not only affect electricity and fuel consumptions but also negative environmental impacts (e.g. gaseous emissions such as particulate matter, nitrogen oxides, sulfur oxides and greenhouse gases) of conventional power generation units and the end-uses of the households. In this paper, only greenhouse gas emissions, represented by carbon dioxide, will be evaluated as a result of employing efficient practices. The projected reduction in CO_2 emissions can be calculated based on direct relationship between electricity generation, fuel consumption and CO_2 emissions: higher rate of consumption means more CO_2 released to the atmosphere. Previously listed specific CO_2 emission coefficients will be taken in this study [27].

3.3. Time series analysis

In order to use developed models (Eqs. (3)–(8)), the predicted future fuel and electricity consumptions of the residential sector is required. Such consumption can be generated using a forecasting tool based on time series technique. The analysis of historical fuel and electricity consumptions of the residential sector over the period 1985–2006 shows an evident long-run trend similar to that seen in Fig. 5. The double exponential smoothing forecasting time series method is recommended in such situations [30]. The double exponential forecasting equation is as follows:

$$F_{t+m} = a_t + b_t m \tag{9}$$

where F_{t+m} is the forecast, m the number of periods ahead to be forecast, a_t the forecasted intercept, and b_t the forecasted slope. The intercept a_t and the slope b_t are estimated as follows:

$$a_t = 2S'_t - S''_t \tag{10}$$

$$b_t = \frac{\alpha}{1-\alpha}(S'_t - S'') \tag{11}$$

$$0 \le \alpha \le 1 \tag{12}$$

where α is the smoothing constant used to weight current and past observations, and S'_t and S''_t the single and double exponential smoothing values respectively for time t. These S'_t and S''_t values are calculated as follows:

$$S'_t = \alpha X_t + (1-\alpha)S'_{t-1} \tag{13}$$

$$S''_t = \alpha S'_t + (1-\alpha)S''_{t-1} \tag{14}$$

The higher α means more weight is given to the most recent observations. Before running the analysis, α should be selected. The forecasts for electricity and fuel consumptions are calculated using different α's, and the α that gives a small mean square error for the forecasts and shows an expected future growth is chosen. In addition to choosing appropriate α, values of S'_{t-1} and S''_{t-1} must be assumed when $t = 1$ since no such values exist for this period. This problem can be solved by assuming that both values are equal to the initial historical data since α values for both fuel and electricity consumptions are larger than zero and the number of data points is more than 20 [30,31].

3.4. Data sources

Historical data, during the studied period 1985–2006, were utilized to develop the multivariate linear regression models of fuel and electricity consumptions of the Jordanian residential sector. Electricity and fuel consumptions and fuel retail prices as well as electricity tariff were obtained from the Ministry of Energy and Mineral Resources [32]. The Gross Domestic Product (GDP) values were obtained from the Central Bank of Jordan [33]. A change in the GDP from 1 year to another includes an increase (or decrease) in price resulting from inflation (deflation). Therefore, before using estimates of the GDP values, these were adjusted for the effect of changes in prices using the consumer price index (2002 constant prices) obtained from the Central Bank of Jordan [34]. Population values were taken from the Department of Statistics [35], while the temperature values were collected from the Metrological Department [36]. Table 2 summarizes complete set of data used in building the multivariate regression models.

4. Results and discussion

4.1. Multivariate regression analysis results

A multivariate regression analysis software package, Minitab, is used to estimate the coefficients (μ's) associated with each variable shown in Eqs. (1) and (2), and to test their significance. This software tests also significance of the multivariate linear regression model using the ANalysis Of VAriance (ANOVA), which is based on the least square method [28]. Using this technique, fuel price, income level, and population are the most important variables that affect demand on electrical power, while population is the most important variable for the fuel consumption case. Table 3 demonstrates the ANOVA analysis for fuel and electricity models, noting that variables included in models are significant since the p-value associated with each parameter is 0.00 [25,27,28]. In order to verify the multivariate linear regression models, its adequacy and performance should be checked:

- *Assumption validation*: The ANOVA tool used in the multivariate linear regression analysis to testify the validity and significance of the model is based on some assumptions, such as residuals

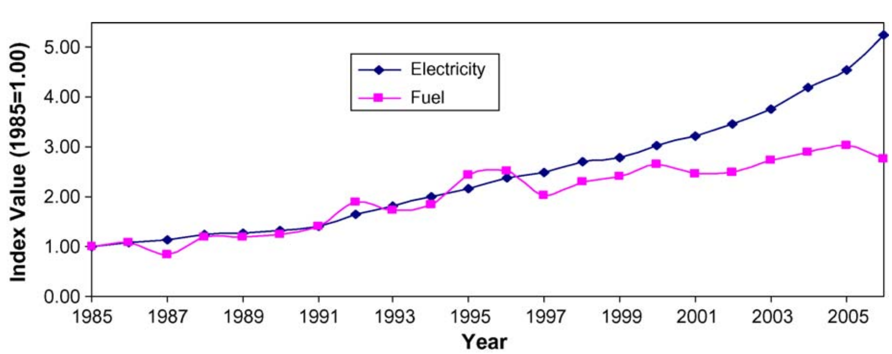

Fig. 5. Indices values of historical fuel and electricity consumptions of the Jordanian residential sector.

Table 2
Data set for the residential sector multivariate linear regression models.

Year	Electricity (GWh)	Fuel (1000 toe)	*E*$ ($/kWh)	*F*$ ($/GJ)	TD (°C)	GDP/capita ($/capita)	Population (1000)
1985	655	245	0.069	5.50	10.7	2334	2700
1986	704	264	0.066	5.50	10.8	2542	2805
1987	753	207	0.066	5.50	11.3	2466	2914
1988	821	294	0.065	5.50	12.2	2248	3027
1989	841	289	0.065	6.06	11.2	1703	3144
1990	874	304	0.068	6.06	10.7	1499	3468
1991	928	343	0.068	6.06	10.7	1410	3701
1992	1074	463	0.068	6.35	13.1	1631	3844
1993	1192	426	0.072	6.49	11.9	1658	3993
1994	1317	453	0.072	6.49	12.0	1740	4139
1995	1422	597	0.072	6.49	12.0	1805	4264
1996	1562	615	0.076	6.49	11.5	1720	4383
1997	1628	500	0.076	6.49	12.0	1724	4506
1998	1780	564	0.076	6.77	11.8	1794	4623
1999	1835	591	0.076	6.77	11.0	1792	4738
2000	1981	649	0.076	6.77	12.0	1834	4857
2001	2110	605	0.076	7.76	10.8	1834	4978
2002	2270	611	0.082	8.18	11.6	1880	5098
2003	2471	671	0.082	9.45	12.4	1918	5230
2004	2745	708	0.082	10.15	11.4	2030	5350
2005	2989	741	0.085	12.97	11.0	2119	5473
2006	3435	680	0.085	15.93	10.9	2178	5600

Table 3
Regression summary outputs for the Jordanian residential models.[+]

Electricity[a] (GWh)			Fuel[b] (1000 toe)	
Variable	Coefficient	VIF	Variable	Coefficient
Intercept (GWh)	−2576.4	NA	Intercept (1000 toe)	−263.18
P (1000)	0.644	3.2	*P* (1000)	0.1789
I ($/capita)	0.386	1.4	–[++]	–
F$ ($/MJ)	98.348	3.1	–	–

[a] R^2 = 99.5%, adjusted R^2 = 99.4%, and predicted R^2 = 99.21%.
[b] R^2 = 93.2%, adjusted R^2 = 92.9%, and predicted R^2 = 92.05%.
[+] Significant variables have an approximately zero *p*-value.
[++] Variable is not significant at 0.05 *p*-value.

having constant variance and being normally distributed. A graphical analysis of the residuals was carried out for each of the regression models to check the validity of such assumptions. As an example, Fig. 6(a) and (b) shows the residual versus fitted values, and the normal probability plot for the Jordanian fuel consumption model. The analysis demonstrates satisfactory results since residuals are contained within a horizontal band, i.e. the constant variance assumption is satisfied, and since the cumulative normal distribution is approximately a straight line, i.e. the normality assumption is also satisfied.

- *Outlier, leverage and influence points diagnosis (unusual points)*: No outlier, leverage, and influential points were detected in any of the regression models.
- *Multicollinearity*: Large *variation inflation factors* (*VIFs*), usually larger than 10 [28], indicate that the associated regression coefficients are poorly estimated because of multicollinearity. The latter indicates that near-linear dependencies among the regression variables can lead to misleading results. A shown from Table 3, the *VIF* for the parameters is less than 10; which is an indication that the multicollinearity does not exist in the model.
- *Goodness-of-fit*: The model seems to reasonably represent the behavior of the data since the values of the coefficient of multiple determination (R^2), adjusted R^2, and predicted R^2 statistics are very high as shown in Table 3. These are the most popular measures of goodness-of-fit.
- *Analysis of model coefficient signs*: The coefficients in the final models should be studied to determine if their signs are reasonable. As can be seen from Table 3, the positive sign of fuel price, income level, and population are expected for the electricity consumption model as well as the positive sign for the population variable in the fuel consumption model. As the population increases, each inhabitant requires additional electricity and fuel in the form of space cooling and/or heating, domestic hot water, lighting, etc., and thus rates of electricity and

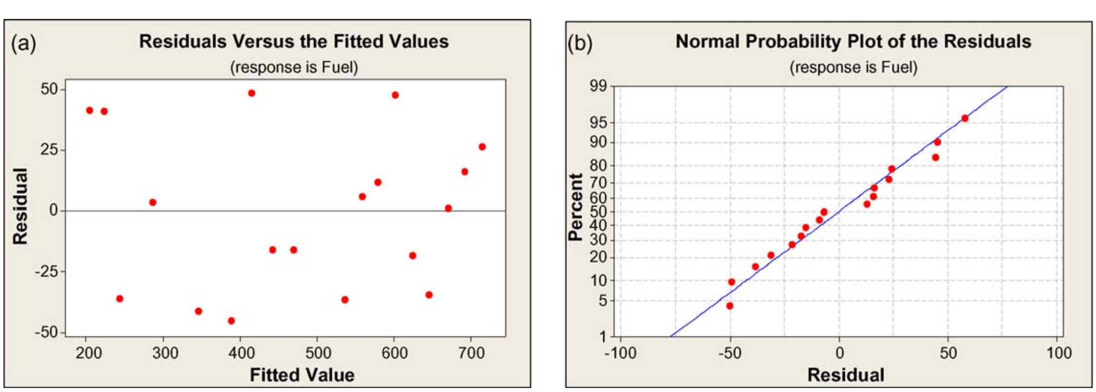

Fig. 6. (a) Residual vs. fitted values and (b) normal probability plot, for the Jordanian residential fuel consumption model.

fuel consumption would increase. As per capita income levels increased, it is expected to witness higher appliance saturation rates in houses, larger and higher quality appliances, and higher appliance utilization rates. Consequently, rates of electricity consumption would rise. Finally, as fuel prices increased, most of people will respond by switching to other available forms of energy such as electricity as a substitute to fuel being used; and therefore, electricity consumption should increase. The latter was observed last 2 years, i.e. 2006–2007, when the prices of different fuels were increased significantly and leaving electricity tariff unchanged. Jordanians understood the message and they relied more on electricity for space and water heating instead of petroleum products [37].

From the preceding tests, one can conclude that the suggested model does not violate main assumptions and represent data accurately. The complete equations for electricity and fuel consumption models are as follows:

$$(\hat{E})_t = -2576.4 + 0.6443P_t + 0.386I_t + 98.348F\$_t \quad (15)$$

$$(\hat{F})_t = -263.18 + 0.17892P_t \quad (16)$$

where $(\hat{E})_t$ is the estimated electricity consumption in year t (GWh) and $(\hat{E})_t$ is the estimated fuel consumption in year t (1000 toe).

4.2. Impacts of adopting energy efficiency strategy

The clear energy economy and emission advantage that high efficiency measures have over their conventional counterparts can be one of the answers offered to alleviate the worsening energy crisis in Jordan on one hand and to improve CO_2 emission intensity, i.e. reduce total emissions. Unfortunately, many types of appliances that are employed in most of local Jordanian houses are not energy efficient, or designed to be energy efficient, especially in low-income households who are naturally in need for reduced energy bills due to tight energy budget. It is important to emphasize that poor families should be considered as natural partners for a demand-side strategy that could perhaps even stimulate energy management strategies in other sectors. Furthermore, there is also a lack of understanding on the management level, of the importance of energy thrift and environmental protection as well as the vulnerability of the economy to the availability of commercial energy resources at reasonable prices.

Electric water heaters and lighting are main consumers of electricity in the residential sector, with an average share of about 29% of total electricity consumed in residential sector. Water heaters fuelled by LPG and diesel represent approximately 9% of the total fuel consumption of the residential sector [13]. Any improvement in the efficiency of these end-uses would result in reduced costs, enhanced efficiency, as well as healthier environment.

4.2.1. High efficiency lightings

Replacement of old conventional end-uses with their corresponding high efficiency alternatives represents a great opportunity for improving the efficiency of the residential sector. This can be achieved only by encouraging or pushing consumers' to buy and use more efficient appliances through implementing a minimum energy efficiency standard for these appliances. Such programs are now becoming mandatory in many countries [9]. By minimum energy efficiency standard, the appliances must meet a specified energy efficiency level before they can be legally sold. The successful experiences of some countries in this field such as follows: China, Canada, Australia, and Malaysia have been documented [8,9,38,39]. Unfortunately, Jordan does not have such standards yet, but an energy efficiency labeling standard is used for comparison purposes only, such as those for lightings and refrigerators [40,41]. With the continuous increase in the overall appliances ownership and energy consumption in Jordan, the adoption of minimum energy efficiency standards can be highly effective in controlling electricity demand in the residential sector. The present work aims to attract the attention of policy makers in Jordan, and in other countries, to such standards by providing quantitative values concerning savings that can be achieved, starting with the example of high efficiency lightings.

Al-Ghandoor et al. [13] found that T-8 fluorescent and incandescent lamps are the most familiar source of lights and are widely used in the Jordanian residential sector. Lighting electrical consumption was found to be approximately equally divided between T-8 fluorescent and incandescent bulb types. However, the T-8 fluorescent lamps can be considered efficient compared with incandescent lamps. The popularity of the incandescent lamps is due to the simplicity with which it can be used and more importantly low cost of both of pulp and its fixture. Also, the lamp requires no special equipment, like a ballast, to modify the characteristics of its power supply or a starter. Unfortunately, based on results obtained from recent field survey, the use of high efficiency compact fluorescent lamps is not widely used and can be considered negligible [13]. In this paper, the use of compact fluorescent lamps as a replacement to the ordinary incandescent lamps is recommended. The size of these lamps is very similar to that of ordinary incandescent lamps, but they have a life 10 times longer, and reduce electricity consumption by about 80%. Table 4 summarizes the resulting electricity savings and net reduction in GHG emissions for the different scenarios explained before. The future electricity consumptions were obtained by applying the double exponential smoothing technique as explained before using a value of α equal to 0.83.

4.2.2. Solar water heating systems

Electricity, diesel, and LPG are the main energy sources used for water heating in Jordan which thereby contribute significantly to air pollution and build-up of carbon dioxide in the atmosphere. Despite the fact that 17% of dwellings in Jordan use SWH systems [42], water heaters are major energy consumers for Jordan's residential sector. Fortunately, Jordan enjoys high average of solar radiation and about 300 sunny days per annum; therefore, the potential for utilizing solar water heaters is high. Estimated energy savings for domestic water heating, resulting from installation of solar heaters instead of using individual electric, LPG, and diesel water heaters are summarized in Tables 5 and 6 for the different scenarios explained before. The future fuel consumptions were obtained by applying the double exponential smoothing technique as explained before using α as 0.33.

4.2.3. Savings summary

Table 7 and Figs. 7 and 8 summarize predicted future energy and cost savings as well as CO_2 emissions for different scenarios analyzed in this simulation study, where electricity values in Tables 4 and 5 were converted into their equivalent final energy, i.e. dividing by the weighted average electricity generation efficiency (i.e. 35%).

As can be seen from Fig. 7, for scenario A, business as usual, it is obvious that residential energy consumption would grow by approximately 62% by year 2018 as compared to base year 2008. But when efficient practices are introduced, energy consumption is predicted to rise at a lower rate, reaching 51.0%, 56.5%, 55.9%, and 58.9% for scenarios B, C, D, and E, respectively, for same period. This

Table 4
Electricity savings and environmental impacts by implementing high efficiency lightings.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Scenario A (GWh)	4197	4581	4965	5349	5733	6118	6502	6886	7270	7654	8038
Scenario B											
Electricity savings (GWh)		57	114	171	228	285	341	398	455	512	569
Cost savings (M$)		8.0	16.1	24.1	32.2	40.2	48.2	56.3	64.3	72.3	80.4
Installed capacity savings (M$)		35.1	70.2	105.3	140.4	175.6	210.7	245.8	280.9	316.0	351.1
Carbon dioxide reduction ($\times 10^6$ kg)		26	53	79	105	131	158	184	210	237	263
Scenario C											
Electricity savings (GWh)		28	57	85	114	142	171	199	228	256	285
Cost savings (M$)		4.0	8.0	12.1	16.1	20.1	24.1	28.1	32.2	36.2	40.2
Installed capacity savings (M$)		17.6	35.1	52.7	70.2	87.8	105.3	122.9	140.4	158.0	175.6
Carbon dioxide reduction ($\times 10^6$ kg)		13	26	39	53	66	79	92	105	118	131
Scenario D											
Electricity savings (GWh)		6	17	34	57	85	120	159	205	256	313
Cost savings (M$)		0.8	2.4	4.8	8.0	12.1	16.9	22.5	28.9	36.2	44.2
Installed capacity savings (M$)		3.5	10.5	21.1	35.1	52.7	73.7	98.3	126.4	158.0	193.1
Carbon dioxide reduction ($\times 10^6$ kg)		3	8	16	26	39	55	74	95	118	145
Scenario E											
Electricity savings (GWh)		3	9	17	28	43	60	80	102	128	156
Cost savings (M$)		0.4	1.2	2.4	4.0	6.0	8.4	11.3	14.5	18.1	22.1
Installed capacity savings (M$)		1.8	5.3	10.5	17.6	26.3	36.9	49.2	63.2	79.0	96.6
Carbon dioxide reduction ($\times 10^6$ kg)		1	4	8	13	20	28	37	47	59	72

would yield an estimated annual cost savings of about 61.4 million US$ for the most conservative scenario (E) as shown in Table 7. In addition, the total installed capacity cost savings is estimated to be around 1237.6, 618.8, 680.7, and 340.3 million US$ for scenarios B, C, D, and E, respectively, by year 2018 as shown in Table 7. Such reductions would help to postpone a portion of the needed investment for adding new generation units, and thereby lower the long-run marginal cost of electricity generation and expansion in supply side. It is a proven fact that the investment in energy saving is much more cost effective than that for adding the same requested capacity, especially when it comes to low cost measures such as those considered in this study. Equally important is that such actions would also release the scarce capital investment, which is urgently needed for social and economic development in Jordan. From the pollution reduction point of view, CO_2 emissions would rise by approximately 58.8% as shown in Fig. 8 by year 2018 as compared to base year 2008 for scenario A. But when efficient practices are introduced, such emissions are expected to grow at a lower rate, reaching 40.8%, 49.8%, 48.9%, and 53.9% of the value considered for base year for scenarios B, C, D, and E, respectively, by year 2018. This would yield estimated annual emission reductions of 656×10^3, 328×10^3, 361×10^3, and 180×10^3 ton for the studied scenarios. These, as stated in the clean development mechanism (CDM) of Kyoto Protocol, carbon reduction emissions can be considered as a source of wealth generation, in Jordan, since GHG emission has relatively high value in the international market of about 25–30 US$/ton of GHG reduced, at present. Thus, the government of Jordan should give high priority for energy saving programs in different sectors of the economy through establishing a special energy fund to finance and advocate implementation of

Table 5
Electricity savings and environmental impacts by implementing SWH systems.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Scenario A (GWh)	4197	4581	4965	5349	5733	6118	6502	6886	7270	7654	8038
Scenario B											
Electricity savings (GWh)		57	115	172	230	287	345	402	460	517	575
Cost savings (M$)		5.7	11.4	17.0	22.7	28.4	34.1	39.8	45.5	51.1	56.8
Installed capacity savings (M$)		88.6	177.3	265.9	354.6	443.2	531.9	620.5	709.2	797.8	886.5
Carbon dioxide reduction ($\times 10^6$ kg)		27	53	80	106	133	159	186	212	239	266
Scenario C											
Electricity savings (GWh)		29	57	86	115	144	172	201	230	259	287
Cost savings (M$)		2.8	5.7	8.5	11.4	14.2	17.0	19.9	22.7	25.6	28.4
Installed capacity savings (M$)		44.3	88.6	133.0	177.3	221.6	265.9	310.3	354.6	398.9	443.2
Carbon dioxide reduction ($\times 10^6$ kg)		13	27	40	53	66	80	93	106	119	133
Scenario D											
Electricity savings (GWh)		6	17	34	57	86	121	161	207	259	316
Cost savings (M$)		0.6	1.7	3.4	5.7	8.5	11.9	15.9	20.5	25.6	31.3
Installed capacity savings (M$)		8.9	26.6	53.2	88.6	133.0	186.2	248.2	319.1	398.9	487.6
Carbon dioxide reduction ($\times 10^6$ kg)		3	8	16	27	40	56	74	96	119	146
Scenario E											
Electricity savings (GWh)		3	9	17	29	43	60	80	103	129	158
Cost savings (M$)		0.3	0.9	1.7	2.8	4.3	6.0	8.0	10.2	12.8	15.6
Installed capacity savings (M$)		4.4	13.3	26.6	44.3	66.5	93.1	124.1	159.6	199.5	243.8
Carbon dioxide reduction ($\times 10^6$ kg)		1	4	8	13	20	28	37	48	60	73

Table 6
Fuel savings and environmental impacts by implementing SWH.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Scenario A (1000 toe)	746	763	779	796	812	829	845	862	878	895	912
Scenario B											
Fuel savings (1000 toe)		6	11	17	22	28	33	39	44	50	56
Cost savings (M$)		8.6	17.2	25.8	34.4	43.0	51.6	60.2	68.8	77.4	86.0
Installed capacity savings (M$)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carbon dioxide reduction ($\times 10^6$ kg)		13	26	38	51	64	77	89	102	115	128
Scenario C											
Fuel savings (1000 toe)		3	6	8	11	14	17	19	22	25	28
Cost savings (M$)		4.3	8.6	12.9	17.2	21.5	25.8	30.1	34.4	38.7	43.0
Installed capacity savings (M$)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carbon dioxide reduction ($\times 10^6$ kg)		6	13	19	26	32	38	45	51	58	64
Scenario D											
Fuel savings (1000 toe)		1	2	3	6	8	12	16	20	25	31
Cost savings (M$)		0.9	2.6	5.2	8.6	12.9	18.1	24.1	31.0	38.7	47.3
Installed capacity savings (M$)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carbon dioxide reduction ($\times 10^6$ kg)		1	4	8	13	19	27	36	46	58	70
Scenario E											
Fuel savings (1000 toe)		0	1	2	3	4	6	8	10	12	15
Cost savings (M$)		0.4	1.3	2.6	4.3	6.5	9.0	12.0	15.5	19.4	23.7
Installed capacity savings (M$)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carbon dioxide reduction ($\times 10^6$ kg)		1	2	4	6	10	13	18	23	29	35

high efficiency measures and renewable energy sources where their economics are attractive. Without such governmental kick-off, it would be almost impossible to increase utilization efficiency in Jordan, especially in the household sector. For example, targeted leasing schemes could be introduced and enacted to encourage employing efficient lighting and appliances as well as SWH systems.

5. Implications and recommendations for national energy policy makers

Fig. 9 shows the cost of consumed energy and its proportion to the national GDP [43,44]. The relatively high growth rates of energy consumption, and cost ratio to GDP are evident, especially over the past few years. These can be attributed to a mix of factors including economic growth, increasing population due to political instability in some neighboring countries, and improved living conditions. As stated previously the government has cut fuel subsidies six times between April 2002 and April 2006, in an attempt to reflect international prices and completely remove subsidies. Finally in February 2008, the Jordanian government completely removed oil subsidies; which in turn will sharply raise proportion of costs of consumed energy to the GDP in the future, starting this year, i.e. 2008.

The relatively high-energy intensity witnessed in Jordan over the last three decades is mainly due to the expansion in infrastructure and energy intensive industries, such as phosphate and potash mining, fertilizers and cement. However, more recently, Jordan witnessed impressive developments in the commercial and services sectors, which do not consume significant

Table 7
Energy savings and environmental impacts by implementing efficient lighting and SWH systems.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Scenario A (1000 toe)	1754	1862	1971	2080	2188	2297	2405	2514	2623	2731	2840
Scenario B											
Fuel savings (1000 toe)		19	38	58	77	96	115	134	154	173	192
Cost savings (M$)		22.3	44.6	67.0	89.3	111.6	133.9	156.2	178.6	200.9	223.2
Installed capacity savings (M$)		123.8	247.5	371.3	495.0	618.8	742.6	866.3	990.1	1113.8	1237.6
Carbon dioxide reduction ($\times 10^6$ kg)		66	131	197	263	328	394	459	525	591	656
Scenario C											
Fuel savings (1000 toe)		10	19	29	38	48	58	67	77	86	96
Cost savings (M$)		11.2	22.3	33.5	44.6	55.8	67.0	78.1	89.3	100.4	111.6
Installed capacity savings (M$)		61.9	123.8	185.6	247.5	309.4	371.3	433.2	495.0	556.9	618.8
Carbon dioxide reduction ($\times 10^6$ kg)		33	66	98	131	164	197	230	263	295	328
Scenario D											
Fuel savings (1000 toe)		2	6	12	19	29	40	54	69	86	106
Cost savings (M$)		2.2	6.7	13.4	22.3	33.5	46.9	62.5	80.4	100.4	122.8
Installed capacity savings (M$)		12.4	37.1	74.3	123.8	185.6	259.9	346.5	445.5	556.9	680.7
Carbon dioxide reduction ($\times 10^6$ kg)		7	20	39	66	98	138	184	236	295	361
Scenario E											
Fuel savings (1000 toe)		1	3	6	10	14	20	27	35	43	53
Cost savings (M$)		1.1	3.3	6.7	11.2	16.7	23.4	31.2	40.2	50.2	61.4
Installed capacity savings (M$)		6.2	18.6	37.1	61.9	92.8	129.9	173.3	222.8	278.5	340.3
Carbon dioxide reduction ($\times 10^6$ kg)		3	10	20	33	49	69	92	118	148	180

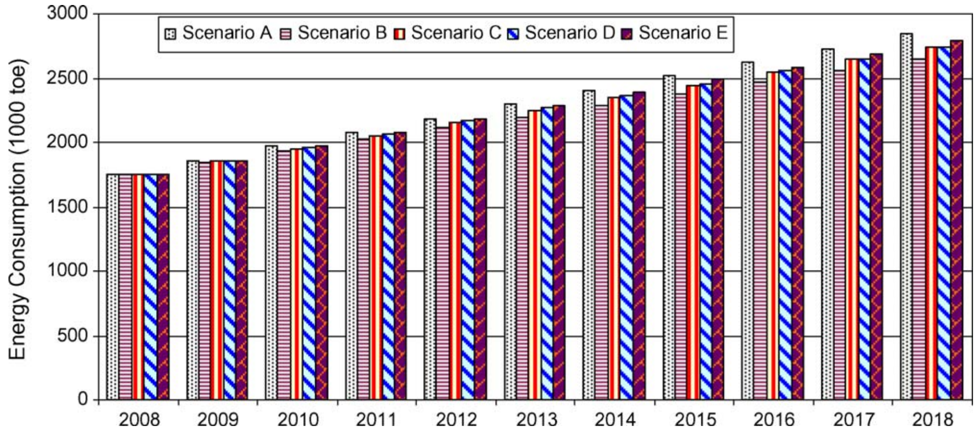

Fig. 7. Predicted future residential annual energy consumption.

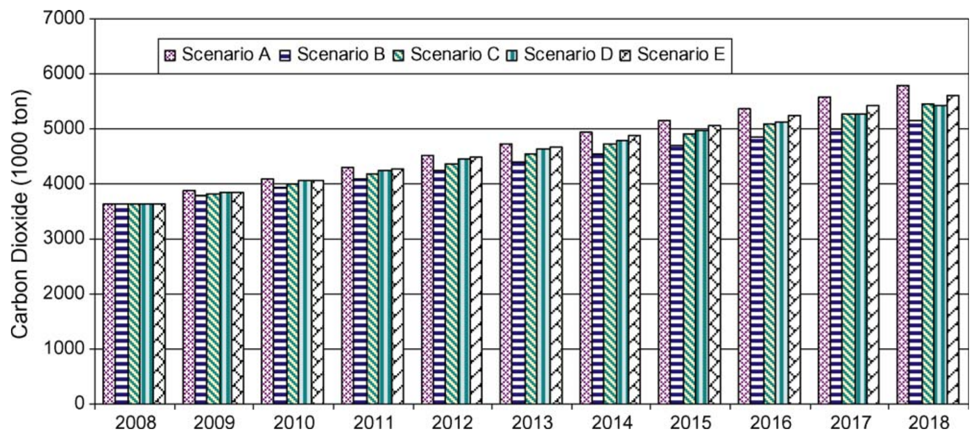

Fig. 8. Forecasted annual rates of carbon dioxide emissions from the residential sector.

amounts of energy but contribute significantly to generating wealth in the country: the economy could now grow without consuming more energy. Sustainable economic growth should not lead to an increased rate of energy consumption. Energy efficiency should be promoted on the highest decision-making level in order to meet long-term energy demands and a comprehensive energy conservation strategy must be established as a main element in the national energy plan. This must take into account the fuel mix and technologies being employed in the different economic sectors. It should include periodic auditing-programs, create incentives to encourage energy conservation, establish an energy-data bank, introduce technical training and public awareness programs, and encourage private-sector participation to invest in energy thrift and renewable energy programs where their economics are attractive especially in the residential sector. However, since the employment of more efficient energy technologies can alter favorably the national energy demand profile, benefit industries and individual consumer's budgets and also contribute towards a cleaner environment, it would be wise that concerned governmental institutions introduce a package of highly efficient appliances, equipment and machinery as part of electrical-connection or fuel-supply agreements for new or targeted

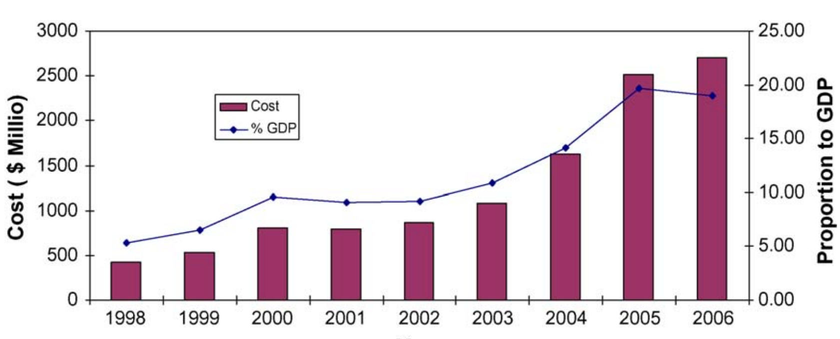

Fig. 9. Cost of consumed energy and proportion to GDP.

customers [45,46]. On the other hand, it is deemed that promoting energy efficiency will help in creating new job opportunities and specialized energy industries and services.

Finally, the government of Jordan has acknowledged in its final energy master plan the desire for improving energy efficiency in all sectors and reducing energy intensity, which is considered as first step towards correcting the prevailed situation during last two decades. However, this will not work alone without introducing proper mechanisms, legal and financial frameworks. Successful implementation of most of energy efficiency programs, that are viable for the case of Jordanian market, requires both the intention and support from the government as well as understanding and participation of energy suppliers and consumers. But scarce national sources of funding for energy management and environmental protection projects and the government's zero budget allocated for advocating wise energy management programs are major barriers for promoting energy efficiency in all sectors of the economy. It is extremely important that all governmental institutions should work closely and cooperate in order to avoid having conflicting aims, especially when it comes to energy and environment, e.g. reduce the financial burden of importing oil and gas and supply energy at the least cost to consumers. Thus, more detailed studies and analysis should be carried out in the near future for different sectors and influence of various variables, including legal and financial issues, on sectorial energy consumption and most likely possibilities to enhance utilization efficiency.

6. Conclusions

This study presents a comprehensive analysis of historical, current, and future fuel and electricity consumption within the residential sector. Two empirical models based on multivariate linear regression technique for electricity and fuel consumptions were developed. These models identify main drivers behind electricity and fuel consumption changes from 1 year to another and have been proved to be adequate with high values of R^2 and adj-R^2. Significant factors affecting electricity consumption have been found to be population, income level, and fuel prices while population is the key factor in the fuel consumption model. One of most important findings of this study is that the developed models suggest that electricity and fuel prices have no effect on electricity and fuel consumptions models respectively. This simply means that people do not respond to any increase in energy prices by adopting more efficient technologies. Such a striking result may be attributed to the fact that, before year 2000, fuel direct and cross subsidies and relatively low residential electricity tariff discouraged householders from investing in efficient and alternative energy sources: there was a general believe among Jordanians that energy is abundant and almost 50% of imported crude oil from Iraq, during 1980–1990s until US occupation in April 2003, was given on free basis and the remaining was paid at special discounted prices. However, the general situation in Jordan is expected to change since the government completely lifted fuel subsidies starting from 8 March 2008.

The paper emphasized that most households, in Jordan, do not employ efficient appliances such as efficient lightings and abundant solar energy. The analysis demonstrated significant potential energy and environmental benefits as a result of adopting high efficiency standards. At worst scenario, it is expected that net savings of approximately 61.4 million US$ per annum, will be achieved by year 2018, if such standards are adopted on gradual basis. Consequently, the associated CO_2 emissions reduction will be approximately 180 millions ton per year. The estimation methods and basic assumptions employed in this paper easily can be modified using different sets of data and assumptions to suit any similar case in other countries. Having listed the advantages of implementing high efficiency lightings and solar water heaters that can lead to electrical and fuel energy conservation, the implementation of such measures is very crucial for Jordanian residential sector to reach desired energy savings. More detailed studies and analyses for all household appliances should be carried out, soon, in order to assess total potential savings which will enable energy planners and policy makers to better understand real challenges in this sector. A paper under preparation now is dealing with minimum efficiency measures for refrigerators, air-conditioning units, and washing machines. Authors believe that this analysis can be applied to other neighboring Arab countries with similar conditions.

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